may be corrected using the pilots as references. Additional stability is also provided using temperature compensation control.

2. Analog Telephony

Even though analog telephone signals are generated in 4 KHz band, transmitting them as 30 KHz FM signals is more efficient than narrowband 4 KHz AM transmission. The CNR required in AM is about 25 dB, whereas the FM channel needs only 12 dB. Even though FM has larger bandwidth, the power required per FM carrier is smaller than that of AM by about 3 dB. Since bandwidth is not a premium but power is, the advantage of FM is clear.

Assuming that 1 GHz bandwidth is allocated for the secondary services, it can be used for 16,600 simultaneous telephone conversations, which is the ideal theoretical limit. If this is the only non-video service, the capacity is large enough to allocate one circuit per customer in most of the service areas. This has the elegance that it virtually parallels the method used in standard telephone systems (except for FM and duplex features). On the other hand, this is very wasteful of the channel spectrum resource.

Terrestrial cellular mobile telephony uses 30 KHz FM transmission, and the hardware used there can also be used for the present application.

Since not all of the 1 GHz bandwidth will be available for telephony, it is useful to consider alternatives. Demand assignment of the (30 KHz) circuits is one way to improve spectral efficiency. This technique is used in cellular systems and hence inexpensive consumer hardware is available.

Recently Motorola has shown that a 30 KHz channel can be used for three telephone speeches using analog modulation; this will increase the capacity to 20,000 conversations in 400 MHz of RF bandwidth within a cell.

3. Transmitting System Requirements for Secondary Services

In order to keep the subscriber equipment costs low, the most important requirement is that the subscriber's transmitting amplifier power should be as low as possible. Hence the amplifier peak power rating should be low and be operated close to saturation.

A baseline system with a near-omni directional antenna, with 10 dBi gain, at the headend, and a 7.5 inch dish antenna at the subscriber's end, is assumed. It is shown earlier that a 100 W TWTA operating at 7 dB backoff can deliver reliable signals over reasonable distances (3 miles in New York and 4.5 miles in Los Angeles). This is equivalent to a transmitting signal level of 0 dBm per 50 KHz, and can be received with a CNR of 13 dB in 50 KHz. Consequently the subscriber's transmitter needs to provide (to the antenna input) a signal of only -2.2 dBm power for a 30 KHz channel which can be received by the headend at a CNR of 13 dB. If the channel bandwidth is 100, 200 and 1140 KHz, the required power levels are 3, 6 and 13.5 dBm respectively. These channels can be used, for instance, to transmit data at rates of 135, 271 and 1544 Kbps, respectively, using an FM-like digital modulation GMSK. The return channel from the headend-to-subscriber also can carry data at the same rates, although this is not essential.

For telephone and other two-way services the link analysis results are provided in Tables III-3.1 to III-3.5 are relevant. These tables give the transmitter power per 30 KHz channel, and the distances over which such channels can be transmitted to achieve a CNR of 13.0 dB under rain faded condition (99.9% availability). This power is seen to be about -2 dBm (0.63 mW). For carriers that require larger bandwidth and a CNR of 13.0 dB, the transmitter power per carrier is increased in proportion to the bandwidth. For instance a carrier with 1 MHz of bandwidth will require an RF power of 20 mW, which is fairly low.

Besides low power, an additional related constraint is that the subscriber's transmitting amplifier be operated close to saturation. This rules out substantially analog AM modulation; other problems with AM are high CNR and low tolerance to interference. An amplifier operating at saturation exhibits substantial out-of-band signal spreading for digital signals, unless they have exactly or nearly constant envelope.

Analog FM carriers with 30 KHz bandwidth are used in terrestrial cellular radio systems. Hence a low cost technically acceptable telephone signal delivery system can be developed using such hardware, which is already available at low cost. The RF portion needs obvious changes; the cellular radio equipment uses upper UHF frequencies, which need to be up and down converted to the millimeter wave frequencies. Since several hundreds of MHz bandwidth is available here, appropriate frequency upgrading and power downgrading of the cellular radio hardware is necessary for full utilization.

As stated earlier digitally modulated signals also should have, at least approximately, constant envelope. One such modulation candidate (recommended by the US Electronic Industries Association for digital cellular systems) is $\pi/4$ - QPSK. If implemented in a bandwidth of 30 KHz, data transmission at a rate of 48.6 Kbps is possible. In a channel that provides a CNR of 13 dB, bit error rates in the range of 10^{-3} to 10^{-4} can be realized before error correction. Another modulation candidate is Gaussian Minimum Shift Keying (GMSK), which is used in the emerging European digital cellular system standard Group Special Mobile (GSM). The GSM standard specifies 200 KHz bandwidth for a data rate of 270.8 Kbps. Such a signal also can provide a bit error rate of 10^{-3} to 10^{-4} when the received CNR is 13 dB.

The EIA standard channel can support three telephone channels with digitized speech in one 30 KHz carrier. The GSM carrier can support eight telephone channels. Adoption of these standards is highly recommended since inexpensive IF and baseband hardware will exist. By upgrading such hardware, higher speed data can also be transmitted economically (up to T1 rates).

The two above digital transmission standards are examples of time division multiplexing (TDM) systems. There are many other examples of TDM and of telephone or data channels. They are used in satellite communications, rural telephony, and the emerging ISDN standards.

The two-way communication network based on the above principles can carry traffic of different types segregated into different parts of the 1 GHz total available bandwidth. These include analog or digital telephone carriers for residential users, computer data from residential and business users, large volume traffic from business users, PBX to public network links, computer-to-computer dedicated links, etc. The system can be designed to start with any one of these services and expanded to other services in a phase manner.

For non-telephone wideband data services, constant or near constant envelope modulation may be used. Modulation methods, such as $\pi/4$-QPSK or GMSK, produce low out-of-band energy when transmitted through the nonlinear RF transmitting amplifier at the subscriber's premises in the subscriber-to-headend link. For digital video of teleconference quality a 200 KHz GMSK channel transmitting 270 Kbps of data will produce a bit error rate of 10^{-3} to 10^{-4} at a CNR of 13 dB. Larger size digital carriers for PBX and other business traffic can be transmitted similarly using constant or near constant envelope modulations that produce low adjacent channel interference.

The 1 GHz bandwidth, on the polarization (opposite to the video band), can be divided into two approximately equal parts, one for subscriber-to-headend links and the other for headend-to-subscriber links. These frequency bands may contain a mix of two-way traffic signals that will substantially depend upon the traffic requirements within the cells. The headends may be connected to the public switched telephone network.

One important problem in the millimeter wave communication links is the poor frequency stability of RF oscillators. Off-the-shelf oscillators exhibit typically a stability of 20 to 30 parts per million per degree centigrade of temperature. At 28 GHz this is equivalent to frequency drifts of $\pm$ 0.5 to $\pm$ 0.75 MHz. This does not pose a problem for wideband services, such as FM video carriers, assuming that they are over stabilized. However, for narrowband signal transmission, e.g., a data carrier with 200 KHz bandwidth, this level of stability is inadequate. One economical method to solve this problem is to use a set of pilot tones. The pilots can be tracked by receivers and can be used to provide frequency error signals to the local oscillators for down converting received signals and up converting signals for transmission. Similar techniques can also be used at repeaters for efficient frequency translation.

Table III-3.1

Suite 12 System Two-Way Link Analysis
City: New York

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	0.0	38.0
4. Path length, miles	3.0	3.0	.9	3.9
5. Free space loss (at 28 GHz), dB	135.1	135.1	37.3	137.3
6. Receiver antenna gain, dBi	32.0	10.0	8.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	28.2	28.2	32.0	32.0
11. Rain rate for 0.01% mm/hr	52.4	52.4	52.4	52.4
12. Rain attenuation (99.9% availability), dB	15.0	15.0	18.6	18.6
13. Rain faded CNR[1], dB	13.0	13.0	13.2	13.2

[1] Includes intermodulation noise at a C/IM of 27 dB

Table III-3.2

Suite 12 System Two-Way Link Analysis

City: Chicago

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	3.0	3.0	3.9	3.9
5. Free space loss (at 28 GHz), dB	135.1	135.1	137.3	137.3
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	28.2	28.2	32.0	32.0
11. Rain rate for 0.01% mm/hr	52.0	52.0	52.0	52.0
12. Rain attenuation (99.9% availability), dB	14.9	14.9	18.4	18.4
13. Rain faded CNR[1)], dB	3.1	13.1	13.4	13.4

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1) Includes intermodulation noise at a C/IM of 27 dB

Table III-3.3

Suite 12 System Two-Way Link Analysis

City: San Francisco

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	4.5	4.5	6.0	6.0
5. Free space loss (at 28 GHz), dB	138.5	138.5	138.5	138.5
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	24.8	24.8	28.2	28.2
11. Rain rate for 0.01% mm/hr	30.0	30.0	30.0	30.0
12. Rain attenuation (99.9% availability), dB	11.6	11.6	14.3	14.3
13. Rain faded CNR[1], dB	13.0	13.0	13.7	13.7

[1] Includes intermodulation noise at a C/IM of 27 dB

Table III-3.4

Suite 12 System Two-Way Link Analysis

City: Boston

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		**Subscriber Dish Diameter: 15 inch**	
	HS Link	**SH Link**	**HS Link**	**SH Link**
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	3.1	3.1	4.1	4.1
5. Free space loss (at 28 GHz), dB	135.3	135.3	137.8	137.8
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	27.8	27.8	31.5	31.5
11. Rain rate for 0.01% mm/hr	49.0	49.0	49.0	49.0
12. Rain attenuation (99.9% availability), dB	14.4	14.4	18.0	18.0
13. Rain faded CNR[1]), dB	13.2	13.2	13.3	13.3

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1) Includes intermodulation noise at a C/IM of 27 dB

Table III-3.5

Suite 12 System Two-Way Link Analysis

City: Los Angeles

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	4.5	4.5	6.0	6.0
5. Free space loss (at 28 GHz), dB	138.5	138.5	138.5	138.5
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	24.8	24.8	28.2	28.2
11. Rain rate for 0.01% mm/hr	30.0	30.0	30.0	30.0
12. Rain attenuation (99.9% availability), dB	11.6	11.6	14.3	14.3
13. Rain faded CNR[1], dB	13.0	13.0	13.7	13.7

[1] Includes intermodulation noise at a C/IM of 27 dB

4. Digital Transmission Based Services

Switching and concentration equipment at the headend will be digitally based and hence there is an advantage to transmitting digitized speech over the links between the subscriber and the headend. Economical methods of generating digitized (and compressed) speech will be available in the future when digital TELCO local loops and digital cellular systems become popular. Using compressed speech three sources can be time division multiplexed to generate 48 Kbps (this is the emerging North American digital cellular standard). The 48 Kbps bit stream can be transmitted on a QPSK link that occupies 30 KHz bandwidth. The link requires 12 dB of CNR.

Other digital based services may require data rates varying from 19.2 Kbps to 45 Mbps, with 1.54 Mbps (T1 rate) likely to be the most popular. Such links can use QPSK or GMSK modulation, described below. Recently Motorola has shown that a 30 KHz channel can be used for three telephone speeches using analog modulation; this will increase the capacity to 20,000 conversations in 400 MHz of RF bandwidth within a cell.

Section IV
Conclusions

Because of the considerations described in this report, it is recommended that the video system be of the following type:

- Frequency modulated video channels
- 100 Watt TWTA at the transmitter, operated at 7 dB output backoff
- Transmitter antenna gain of 10 dB
- Receiver dish diameters 15 inch and/or 7.5 inch
- RF bandwidth allocated for video to be minimum 1 GHz
- Capacity of the system is 49 FM channels which are 20MHz wide
- Maximum cell diameter for
- 49 carriers, 15 inch receiver dish: 7.8 miles (NY), 12.4 miles (LA)
- 49 carriers, 7.5 inch receiver dish: 6 miles (NY), 9 miles (LA)
- Clear weather video SNR = 55 dB (minimum among all of the above)
- Faded SNR = 42 dB
- Rain availability is 99.9% in an average year
- Unavailability or reduced picture quality in fringe areas is 8.76 homes/year

Note that the unavailability of the Suite 12 system is better than that required for satellite transmissions. Satellite unavailability is the limiting factor for Suite 12 and cable distribution systems.

Minor modifications to DBS satellite (indoor unit) receiver with an IF that is 1 GHz in bandwidth (e.g. 950 to 2050 MHz) can be used for this purpose. Since many receivers are already equipped with 18 MHz filtering options, no new components need be developed. If video scrambling and pay-per-view options are required, several vendors already provide these options. The FM receiver units also come with automatic frequency control (AFC), the pull-in range of which is adequate to compensate for RF local oscillator frequency instabilities. The outdoor unit of the consumer receiver can be assembled with off-the-shelf equipment. An inexpensive version is under development at Sarnoff.

The FM transmission headend, consisting of video sources, FM modulators and RF amplifiers (100 W TWTA) can be assembled with off-the-shelf equipment provided by several manufacturers.

Rain depolarization, fade margins, and multipath are not a problem for short range millimeter wave propagation and reception by antennas that have narrow beamwidths. The proposed system would come under this category. The quality of the video will be excellent under clear weather condition (SNR in excess of 55 dB), and good even under rain faded condition (SNR of 42 dB).

Two-way communication links between the headend and subscribers have been economically established and demonstrated using low power transmitters, e.g., 5 to 10 mW transmitter power at the antenna input for a channel with 200 KHz bandwidth. These links can be used for analog or digital telephones, computer data and digital video services. By using hardware from emerging or established standards, e.g., analog and digital cellular radio systems, it is possible to develop economically the communication network in a phased manner. By relying on these standards the necessity to develop custom hardware is substantially reduced at all parts of the network, except RF transmission subsystems. Principles of millimeter wave transmission, in the context of the Suite 12 system are verified in this report and have been experimentally demonstrated at both Sarnoff and Suite 12. The inexpensive video hardware designed for the production quantities portion of this program continues in progress. The development of inexpensive two-way hardware is part of phase 3 of this program.

APPENDICES

A-1. Rain Attenuation Prediction Models

To determine rain fade margin we consider two prediction models. The first is the Crane model (IEEE Trans. Comm., Sept.,1980). Let

R	=	Rain rate in mm/hr for a given availability requirement
a	=	$3.8 - 0.6 \ln R$
b	=	$2.3\, R^{-0.17}$
c	=	$0.026 - 0.03 \ln R$
u	=	$\{\ln[b \exp(ac)]\}/a$
D_0	=	22.5 Km
α, β	=	constants that depend on frequency
A	=	Attenuation in dB for a path of length D, Km

Then

$$A = (\alpha R^{\beta})[\exp(u\beta D)-1]/(u\beta) \qquad \text{if } D < a$$

$$= (\alpha R^{\beta})[\{(\exp[u\beta a]-1)/(u\beta)\}$$
$$- \{b^{\beta}(\exp[c\beta a])/(c\beta)\}$$
$$+ \{b^{\beta}(\exp[c\beta D])/(c\beta)\}] \qquad \text{if } a \leq D \leq D_0$$

The condition of $D > D_0 = 22.5$ Km is of no interest here. At 28 GHz, the values of α and β are

$$\alpha = 0.1472$$

$$\beta = 1.081$$

The continental US is divided into rain regions, and for each region values of rain rate R are specified for several unavailability values; see Figure A-4.1 and Table A-1.1.

Table A-1.2 shows the attenuation values for 99.9%, 99.95%, 99.98%, and 99.99% availabilities in different rain regions, for D = 2 to 8 miles.

The second rain attenuation prediction model is the CCIR 1982 model (Report 338-4, paragraph 5.2). Rain regions similar to the Crane regions are developed by the CCIR. However, it is more accurate to use the rain rate contours (0.01% of the time) shown in Figure A-1.2.

Given the rain rate R corresponding to 0.01% of the time, the attenuation at this unavailability level is

$$A(0.01\%) = (\alpha R^{\beta})\, Dr$$

where

α = 0.1618, at f = 28 GHz

β = 1.037, at f = 28 GHz

D = path distance in Km

r = 90/(90 + 4D)

At other unavailability p (percent) values, the attenuation is given by

$$A(p \text{ percent}) = [A(0.01\%)]\,(p/0.01)^{-0.41}$$

where

$$0.01\% \leq p \leq 0.1\%$$

Table A-1.3 shows the attenuation values for several values of p, 0.01% rain rate R, and distances D.

In this study we selected New York and Los Angeles as cities with high population density and where wireless cable TV distribution has significant opportunity for deployment. For rain availability, a service level of 99.9% in an average year is chosen. This is somewhat better than typical DBS (WARC '77) specifications of 99% availability in the worst month of an average year. If the following relation

$$p = 0.29(p_w)^{1.15}$$

is used to relate the average year unavailability time percentage p, and the unavailability p_w in the worst month of an average year, then p = 0.1% corresponds to p_w = 0.396%, i.e., 1-p_w equals 99.6%.

A comparison of the Crane and the CCIR (1982) methods can be made at New York and Los Angeles for 99.9% average year availabilities. Let the path radius, D, be 4 miles at New York and 6 miles at Los Angeles. Then the attenuation values can be computed to be

New York, 4 miles:	Crane Model attenuation = 20.36 dB
	CCIR Model attenuation = 19.03 dB
Los Angeles, 6 miles:	Crane Model attenuation = 13.02 dB
	CCIR Model attenuation = 14.41 dB

It is then seen that the models are in reasonable agreement, at least at these two cities and for the assumed availability level. (In making this comparison, the 0.01% rain rates at New York and Los Angeles are assumed to be 52.4 and 30 mm/hr respectively. At Sarnoff a complete data base of the rain rates obtained from Fig. A-1.2 exists. The New York rain rate, obtained by numerical interpolation is 52.38 mm/hr.) Such agreement cannot be expected at all cities, since Crane's model has wide regions within which the predicted attenuations would be constant, but the CCIR model has finer rain rate variations. In this study we will use the CCIR model, which has a much simpler distance-dependent factor [90D/(90 + 4D)], than the Crane model. Note that the faded rainfall attenuation factor for the radius of the cell need not be changed for application to the diameter of the cell since the transmitter radiates equally in all directions. For the purposes of this study we assumed a worst-case situation in which the maximum rainfall intensity was the same throughout the cell. In reality, rainfall over a large area is not homogeneous and the maximum is usually limited to a diameter of less than one mile. Additionally, the Bossard analysis allows for an increase in transmitter power when the rainfall is heavy. This study does not take into account this factor, which would increase the availability. The results of this study are considered to be very conservative.

TABLE A-1.1
POINT RAIN RATE DISTRIBUTION VALUES

Percent of Year	Rain Climate Region A	B	C	D_1	D_2	D_3	E	F	G	H
0.001	28	54	80	90	102	127	164	66	129	251
0.002	24	40	62	72	86	107	144	51	109	220
0.005	19	26	41	50	64	81	117	34	85	178
0.01	15	19	28	37	49	63	98	23	67	147
0.02	12	14	18	27	35	48	77	14	51	115
0.05	8.0	9.5	11	16	22	31	52	8.0	33	77
0.1	5.5	6.8	7.2	11	15	22	35	5.5	22	51
0.2	4.0	4.8	4.8	7.5	9.5	14	21	3.2	14	31
0.5	2.5	2.7	2.8	4.0	5.2	7.0	8.5	1.2	7.0	13
1.0	1.7	1.8	1.9	2.2	3.0	4.0	4.0	0.8	3.7	6.4
2.0	1.1	1.2	1.2	1.3	1.8	2.5	2.0	0.4	1.6	2.8
Number of Station Years of Data	0	25	44	15	99	18	12	20	2	11

TABLE A-1.2
CRANE MODEL REGION A & REGION B

Rain Region = A

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	10.5	8.5	5.8	4.0
2.5	13.2	10.8	7.4	5.3
3.0	15.7	12.9	9.0	6.5
3.5	18.2	15.0	10.6	7.6
4.0	20.5	17.0	12.0	8.8
4.5	22.7	18.8	13.5	9.9
5.0	24.8	20.7	14.9	11.0
5.5	26.8	22.4	16.2	12.0
6.0	28.7	24.1	17.5	13.1
6.5	30.5	25.7	18.8	14.1
7.0	32.2	27.2	20.0	15.1
7.5	33.9	28.7	21.2	16.1
8.0	35.4	30.1	22.4	17.1

Rain Region = B

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	13.1	9.9	6.8	5.0
2.5	16.3	12.4	8.7	6.4
3.0	19.4	14.8	10.5	7.8
3.5	22.3	17.1	12.2	9.2
4.0	25.0	19.3	13.9	10.5
4.5	27.6	21.4	15.5	11.8
5.0	30.0	23.4	17.1	13.0
5.5	32.3	25.3	18.6	14.3
6.0	34.5	27.2	20.0	15.4
6.5	36.6	28.9	21.4	16.6
7.0	38.6	30.6	22.8	17.7
7.5	40.4	32.2	24.1	18.8
8.0	42.2	33.7	25.3	19.9

TABLE A-1.2
CRANE MODEL REGION C & REGION D1

Rain Region = C

	Availability (%)			
Dist (mi)	99.99	99.98	99.95	99.90
2.0	18.8	12.5	7.9	5.2
2.5	23.1	15.6	10.0	6.8
3.0	27.2	18.5	12.0	8.2
3.5	31.0	21.2	13.9	9.6
4.0	34.6	23.9	15.8	11.0
4.5	38.0	26.4	17.5	12.4
5.0	41.1	28.7	19.3	13.7
5.5	44.1	31.0	20.9	14.9
6.0	46.8	33.1	22.5	16.1
6.5	49.4	35.1	24.0	17.3
7.0	51.8	37.0	25.5	18.5
7.5	54.1	38.8	26.9	19.6
8.0	56.3	40.5	28.2	20.7

Rain Region = D1

	Availability (%)			
Dist (mi)	99.99	99.98	99.95	99.90
2.0	24.3	18.2	11.2	7.9
2.5	29.7	22.4	14.0	10.0
3.0	34.7	26.4	16.7	12.0
3.5	39.4	30.1	19.2	13.9
4.0	43.7	33.6	21.6	15.8
4.5	47.8	36.8	23.9	17.5
5.0	51.5	39.9	26.1	19.3
5.5	55.1	42.8	28.2	20.9
6.0	58.3	45.5	30.2	22.5
6.5	61.4	48.0	32.0	24.0
7.0	64.2	50.4	33.8	25.5
7.5	66.8	52.7	35.5	26.9
8.0	69.3	54.8	37.2	28.2

TABLE A-1.2
CRANE MODEL REGION D2 & REGION D3

Rain Region = D2

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	31.4	23.1	15.1	10.5
2.5	38.1	28.3	18.6	13.2
3.0	44.3	33.1	22.0	15.7
3.5	50.0	37.6	25.2	18.2
4.0	55.3	41.7	28.3	20.5
4.5	60.2	45.6	31.1	22.7
5.0	64.7	49.3	33.8	24.8
5.5	68.9	52.7	36.3	26.8
6.0	72.8	55.8	38.7	28.7
6.5	76.4	58.8	41.0	30.5
7.0	79.7	61.5	43.1	32.2
7.5	82.7	64.1	45.1	33.9
8.0	85.5	66.5	47.0	35.4

Rain Region = D3

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	39.4	30.8	20.7	15.1
2.5	47.6	37.4	25.4	18.6
3.0	55.0	43.5	29.7	22.0
3.5	61.9	49.2	33.9	25.2
4.0	68.2	54.4	37.7	28.3
4.5	74.0	59.2	41.3	31.1
5.0	79.4	63.7	44.6	33.8
5.5	84.3	67.8	47.8	36.3
6.0	88.7	71.6	50.7	38.7
6.5	92.9	75.1	53.5	41.0
7.0	96.7	78.4	56.0	43.1
7.5	100.1	81.4	58.4	45.1
8.0	103.3	84.2	60.7	47.0

TABLE A-1.2
CRANE MODEL REGION E & REGION F

Rain Region = E

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	58.5	47.2	33.1	23.1
2.5	70.0	56.7	40.1	28.3
3.0	80.4	65.4	46.6	33.1
3.5	89.9	73.4	52.6	37.6
4.0	98.6	80.7	58.1	41.7
4.5	106.4	87.3	63.2	45.6
5.0	113.5	93.4	67.9	49.3
5.5	119.9	98.9	72.3	52.7
6.0	125.8	104.0	76.3	55.8
6.5	131.1	108.6	80.0	58.8
7.0	135.9	112.8	83.4	61.5
7.5	140.2	116.7	86.5	64.1
8.0	144.2	120.2	89.4	66.5

Rain Region = F

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	15.7	9.9	5.8	4.0
2.5	19.4	12.4	7.4	5.3
3.0	22.9	14.8	9.0	6.5
3.5	26.2	17.1	10.6	7.6
4.0	29.3	19.3	12.0	8.8
4.5	32.3	21.4	13.5	9.9
5.0	35.0	23.4	14.9	11.0
5.5	37.6	25.3	16.2	12.0
6.0	40.1	27.2	17.5	13.1
6.5	42.4	28.9	18.8	14.1
7.0	44.6	30.6	20.0	15.1
7.5	46.7	32.2	21.2	16.1
8.0	48.6	33.7	22.4	17.1

TABLE A-1.2
CRANE MODEL REGION G & REGION H

Rain Region = G

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	41.6	32.5	21.9	15.1
2.5	50.2	39.5	26.8	18.6
3.0	58.0	45.9	31.4	22.0
3.5	65.2	51.8	35.7	25.2
4.0	71.8	57.2	39.7	28.3
4.5	77.9	62.2	43.5	31.1
5.0	83.4	66.9	47.0	33.8
5.5	88.5	71.2	50.2	36.3
6.0	93.2	75.1	53.3	38.7
6.5	97.4	78.8	56.1	41.0
7.0	101.3	82.1	58.8	43.1
7.5	104.9	85.3	61.3	45.1
8.0	108.2	88.1	63.6	47.0

Rain Region = H

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	83.6	67.4	47.2	32.5
2.5	99.4	80.4	56.7	39.5
3.0	113.6	92.2	65.4	45.9
3.5	126.3	102.9	73.4	51.8
4.0	137.8	112.5	80.7	57.2
4.5	148.1	121.2	87.3	62.2
5.0	157.3	129.1	93.4	66.9
5.5	165.6	136.2	98.9	71.2
6.0	173.0	142.6	104.0	75.1
6.5	179.7	148.5	108.6	78.8
7.0	185.7	153.7	112.8	82.1
7.5	191.1	158.5	116.7	85.3
8.0	196.0	162.7	120.2	88.1

TABLE A-1.3
CCIR RAIN MODEL DATA R = 20.00 & 30.00

R(0.01)% = 20.00

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	10.2	7.7	5.3	4.0
2.5	12.3	9.3	6.4	4.8
3.0	14.4	10.8	7.4	5.6
3.5	16.3	12.3	8.4	6.3
4.0	18.1	13.6	9.4	7.0
4.5	19.8	14.9	10.2	7.7
5.0	21.4	16.1	11.1	8.3
5.5	23.0	17.3	11.9	8.9
6.0	24.4	18.4	12.6	9.5
6.5	25.8	19.4	13.3	10.0
7.0	27.1	20.4	14.0	10.6
7.5	28.4	21.4	14.7	11.0
8.0	29.6	22.3	15.3	11.5

R(0.01)% = 30.00

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	15.5	11.7	8.0	6.0
2.5	18.8	14.1	9.7	7.3
3.0	21.9	16.5	11.3	8.5
3.5	24.8	18.7	12.8	9.6
4.0	27.5	20.7	14.2	10.7
4.5	30.2	22.7	15.6	11.7
5.0	32.6	24.6	16.9	12.7
5.5	35.0	26.3	18.1	13.6
6.0	37.2	28.0	19.2	14.5
6.5	39.3	29.6	20.3	15.3
7.0	41.3	31.1	21.4	16.1
7.5	43.2	32.5	22.4	16.8
8.0	45.1	33.9	23.3	17.5

TABLE A-1.3
CCIR RAIN MODEL DATA R = 40.00 & 50.00

R(0.01)% = 40.00

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	20.9	15.7	10.8	8.1
2.5	25.3	19.1	13.1	9.8
3.0	29.5	22.2	15.2	11.5
3.5	33.4	25.1	17.3	13.0
4.0	37.1	27.9	19.2	14.4
4.5	40.6	30.6	21.0	15.8
5.0	44.0	33.1	22.7	17.1
5.5	47.1	35.5	24.4	18.3
6.0	50.1	37.7	25.9	19.5
6.5	53.0	39.9	27.4	20.6
7.0	55.7	41.9	28.8	21.7
7.5	58.3	43.9	30.1	22.7
8.0	60.7	45.7	31.4	23.6

R(0.01)% = 50.00

Dist (mi)	Availability (%) 99.99	99.98	99.95	99.90
2.0	26.3	19.8	13.6	10.2
2.5	31.9	24.0	16.5	12.4
3.0	37.2	28.0	19.2	14.5
3.5	42.1	31.7	21.8	16.4
4.0	46.8	35.2	24.2	18.2
4.5	51.2	38.5	26.5	19.9
5.0	55.4	41.7	28.6	21.6
5.5	59.4	44.7	30.7	23.1
6.0	63.2	47.5	32.7	24.6
6.5	66.8	50.2	34.5	26.0
7.0	70.2	52.8	36.3	27.3
7.5	73.4	55.3	38.0	28.6
8.0	76.6	57.6	39.6	29.8